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This film heating element

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Thin film heating element

The present invention relates to a film heating element comprising an aluminium substrate, an electrically insulating layer and an electrically resistive layer, as well as to an electrically domestic appliance comprising such heating element.

In general a film heating element consists of two functional layers applied on a substrate, namely, an electrically insulating layer and an electrically resistive layer. Heat is generated by flow of an electrical current through the resistive layer. The function of the insulating layer is, to isolate the heat generating resistive layer from the metal substrate, which may be directly accessible from the outside.

The resistive layer can be electrically contacted with a supply voltage via highly conductive tracks. These conductive tracks are generally patterned.

Flat film heating elements roughly can be divided in two main categories, namely thick film heating elements and thin film heating elements.

The distinction between these two categories concerns the thickness of the resistive layer. Within thick film heating elements, the resistive layer has a thickness exceeding 2 μm . These films are mainly prepared by means of screen-printing techniques. Within thin film heating elements, the resistive layer has a thickness smaller than 2 μm .

These films are mainly prepared by means of evaporation techniques or via pyrolysis of precursor solutions.

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A thin film heating element is known from U.S. Pat. No. 4,889,974. Said patent discloses a thin film heating element prepared by means of a wet-chemical route. This thin film heating element consisted of a resistive layer, which was applied directly on an isolating substrate, like a hard glass substrate, a quartz glass substrate or a ceramic substrate. As a resistive layer a SnO_2 -film doped with acceptor- and donor-forming elements was described. The films were manufactured from a solution by means of a spray pyrolysis process followed by a curing at 600°C.

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A number of patents disclose thin film heaters on electrical conductive substrates like e.g. steel. An insulating layer (e.g. polymer, enamel, etc.) was applied on these

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electrical conductive substrates in order to insulate the resistive layer from the substrate. On top of these insulating layers, a thin resistive layer was applied.

However until recently no thin film heaters on aluminium or aluminium alloy substrates were reported. Aluminium and its alloys have ~~has~~ have a relative large expansion coefficient (22-26 ppm/K) compared to the insulating layers used for steel substrates which are in most cases enamel based insulators. Insulating layers commonly used for steel substrates cannot be used for aluminium (alloy) substrates. Mismatched thermal expansion coefficients result in cracking of the film when the heating element is exposed to temperature cycles. Furthermore, in order to apply these insulators, the precursors are applied on a suitable substrate after which the precursor has to be cured at high temperatures above 650 °C, in order to obtain a suitable insulating layer. These high curing temperatures exceed or are near the melting temperature of aluminium (660 °C) and its alloys. Therefore, these materials are not suitable as electrical insulating layers for aluminium substrates

EP-A-0891118 discloses a thin film heater in which a ceramic layer was used as an insulating layer for an aluminium substrate. However, in this patent the difference in expansion coefficients between the ceramic insulator layer and the aluminium was bridged in that the heating element was first applied onto a stainless steel plate, after which the stainless steel plate was glued onto an aluminium plate with e.g. a silicone based glue.

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It is an aim of the present invention to provide a heating element of the preamble suitable for an aluminium substrate in which no cracks are formed when the element is subjected to temperature cycles. Where the term aluminium is used, it comprises aluminium, anodized aluminium and alloys of aluminium. Furthermore, the present invention aims to provide for an electrical domestic appliance including such a heating element, as well as to a method of manufacturing said heating element.

These and other objects of the invention are achieved, by a film heating element, at least comprising an aluminium substrate, an electrically insulating layer which is based on a sol-gel precursor, and an electrical resistive layer with a thickness smaller than 2 µm.

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By applying a heating element according to the invention several advantages are achieved. First of all no crack formation is observed when the heating element is exposed to temperature cycles between 20 and 300 °C.

Furthermore, the heating element is applicable for high power application, with a power density of 20 W/cm^2 or higher at a substrate temperature of 300°C .

5 The film heating element according to the invention comprises an electrical resistive layer with a thickness smaller than $2 \mu\text{m}$. This resistive layer preferably comprises a metal, a metal oxide or a doped metal oxide. A suitable metal is aluminium. Suitable metal oxides are tin oxide, indium tin oxide (ITO). Suitable doped metal oxides are fluorine or aluminium doped zinc oxide, or tin oxides doped with fluorine or antimony.

10 It has surprisingly been found that although e.g. ITO has a thermal expansion coefficient of about 4 ppm/K compared to about 23 ppm/K for aluminium, no crack formation was observed when the heating element of the invention was exposed to repeated temperature cycles between 20 and 300°C .

The resistive layer can be applied onto the insulating layer by means of (atmospheric) chemical vapor deposition ((A) CVD), physical vapor deposition (PVD), magnetron sputtering, thermal spraying or wet-chemical techniques.

15 The resistive layer preferably consists of an inorganic material. Suitable inorganic materials are a metal, a metal oxide or a doped metal oxide. A suitable metal is aluminium. Suitable metal oxides are tin oxide, indium tin oxide (ITO). Suitable doped metal oxides are fluorine or aluminium doped zinc oxide, or tin oxides doped with fluorine or antimony. Resistive layers of an inorganic material do not risk the formation of a carbonized
20 conductive track.

The heating element of the invention further comprises an electrically insulating layer that is based on sol-gel precursor.

By applying an electrically insulating layer based on a sol-gel precursor several advantages are achieved. First of all, the sol-gel precursor based layer shows
25 excellent electrically insulating properties. The carbon content of a sol-gel precursor based material is sufficiently low to prevent the formation of a carbonized conductive track in case of failure of the heating, thereby providing a safe heating element. Also, sol-gel materials have a high thermal conductivity which is in the order of magnitude of $0.1\text{-}2 \text{ W/m}^\circ\text{K}$. Furthermore, sol-gel precursor can be processed at temperatures below 400°C , which makes
30 this material suitable to be applied directly to aluminium substrates. Due to the lower curing temperature of the hybrid sol-gel precursor the mechanical properties of the aluminium will be maintained. The sol-gel precursor is preferably applied on an anodized aluminium substrate, to ensure good adhesion of the sol-gel layer.

Although the sol-gel insulating layer is especially suitable for application on aluminium substrates, other substrates which are conventionally used for heating elements and which are compatible with the final utility may also be used. Said substrates may include, for example, stainless steel, enameled steel or copper. The substrate may be in the form of a flat plate, a tube or any other configuration that is compatible with the final utility.

Preferably, the sol-gel precursor is a hybrid sol-gel precursor comprising an organosilane compound.

A preferred silane is a silane, forming a hybrid sol-gel precursor. A hybrid sol-gel precursor comprising an organosilane compound is understood to be a compound comprising silicon, which is bond to at least one non-hydrolysable organic group, and 2 or 3 hydrolysable organic groups.

In an advantageous embodiment, the sol-gel material may also comprise silica particles, in particular colloidal silica particles.

In particular, the hybrid sol-gel precursor comprises an organosilane compound from the group of alkyl-alkoxysilanes.

Preferably, the hybrid sol-gel precursor comprises methyl-trimethoxysilane (MTMS) and/or methyl-triethoxysilane (MTES). An advantage of the heating element of the invention based on the hybrid sol-gel system is a relative high power density, and an optimized thermal expansion coefficient values for aluminium.

Hybrid sol-gel precursors such as MTMS and MTES are known to have excellent temperature stability up to at least 450 °C. Moreover MTMS has been shown to prevent silver oxidation and subsequent migration effectively. The carbon content of these materials is still low, so carbonized conductive tracks across the insulating layer will not form after failure, making a safe heating element. The maximum layer thickness of coatings made from hybrid precursors is relatively high, compared to the maximum layer thickness of coatings made from non-hybrid sol-gel materials. Therefore the layers can be deposited in one or at most two steps without intermediate curing.

Advantageously, the electrically insulating layer comprises non-conductive particles.

A fraction of said non-conductive particles preferably have a flake-like shape and a longest dimension of 2-500 µm, preferably from 2-150 µm, and more preferably from 5-60 µm. These flake-like non-conductive particles are based on oxides like for example mica or clay, and/or surface modified mica or clay particles with a coating of titanium dioxide, aluminium oxide and/or silicon dioxide. The flake-like material content in the

insulating layer should be less than 20 vol %, preferably less than 15 volume %, and more preferably less than 4-10 volume %. An advantage of such anisotropic particles is, that their presence prevents the formation of cracks in the electrically insulating layer after frequent heating up and cooling down of the element.

5 In the preferred embodiment, the non-conductive particles are present in colloidal form. Examples thereof are oxides like aluminium oxide and silicon dioxide. Preferably, the aluminium oxide content in the insulating layer should be less than 40 volume %, preferably less than 20 volume %, and more preferably 10-15 volume %. As for the silicon dioxide content in the insulating layer, it should advantageously be less than 50 volume %, 10 preferably less than 35 volume % and more preferably less than 15-25 volume %.

If an insulating layer is based on MTMS or MTES filled with particles, including anisotropic particles, a layer thickness of just 50 μm can withstand 5000V. This relatively small layer thickness allows the temperature difference over the thickness of the resistive layer to be fairly low, which allows for a much lower temperature of the heating 15 resistive layer to obtain a certain temperature of the aluminium substrate. For this reason said thin layers are advantageously used. The layers can be applied by any wet chemical application method, preferably spray coating or screen-printing followed by a curing step.

The heating element according to the invention may further comprise an electrical conductive layer. The electrical conductive layer in the heating element of the 20 invention comprises a layer with a relatively low Ohmic resistance with respect to the electrically resistive layer and acts as a contacting layer between the heat generating resistive layer and an external power source.

The conductive layer may consist of a metal like e.g. aluminium or of a hybrid material such as PI/Ag, or a sol-gel/Ag paste. The conductive layer can be applied by means 25 of (A)CDV, PVD, magnetron sputtering thermal spraying, wet-chemical or screen printing techniques.

The preferred technique for applying the conductive tracks is screen printing. For the conductive track commercially available metal powders can be used. It is preferred to use silver or silver alloy particles

30 Other metal and semiconductors can be used in making conductive layers for the application provided they have sufficiently high temperature stability in the sol-gel matrix. The use of MTMS or MTES precursors reduces the rate of oxidation of silver and graphite particles at high temperatures of the heating element. In that respect it has been

noted that graphite in an MTES derived matrix has shown a stability of more than 600 hours at 320°C.

To make the formulations screen printable, a cellulose derivative can be added to the particle containing, hydrolyzed MTMS or MTES solution. As a cellulose material preferably hydroxyl-propyl-methyl cellulose is used. Finally a solvent with a high boiling point is added to prevent drying of the ink and subsequent clogging of the screen. Butoxyethanol was found to be a suitable choice, but other polar solvents, preferably alcohols, are also found appropriate.

Optionally, the element may be covered with a protective topcoat layer. This topcoat layer mainly serves as a protective layer against mechanical damage during handling of the element. Using for instance silica filled hybrid sol-gel solution, based for example on MTMS, a screen printable formulation can be easily made. The applied topcoat layer can be co-cured with the conductive layer and the resistive layer.

The invention further relates to an electrical domestic appliance comprising at least the heating element of the invention. Heating elements of the present invention are very suitable for heating elements in laundry irons, especially for the controlled formation of steam, for which high power densities are required. However, the heating elements are also very suitable for other domestic applications like hair dryers, hair stylers, steamers and steam cleaners, garment cleaners, heated ironing boards, facial steamers, kettles, pressurized boilers for system irons and cleaners, coffee makers, deep fat fryers, rice cookers, sterilizers, hot plates, hot-pots, grills, space heaters, waffle irons, toasters, ovens or water flow heaters.

The invention also relates to a method of manufacturing a heating element according to the invention, at least comprising the steps of: providing an aluminium substrate; applying an electrically insulating layer on said substrate; and applying a resistive layer on top of the electrically insulating layer, characterized in that the electrically insulating layer is obtained by means of a sol-gel process and the resistive layer has a thickness smaller than 2 µm. In particular the sol-gel process at least comprises the step of mixing an organosilane compound with water.

The invention will further be elucidated in the following manufacturing example.

Example

A 200 nm thin layer (72*64 mm) of ITO (90 wt % In₂O₃, 10 wt% SnO₂ purity more than 99.99%) was applied by means of DC magnetron sputtering in an argon/oxygen

atmosphere with a Leybold Z650 Batch system (start pressure below $4.0 \cdot 10^{-6}$ mBar, deposition speed 20 nm/min.) onto a 50 μm thick insulating layer based on a sol-gel precursor on an aluminium substrate. Conductive layers (PI/Ag based paste, PM437 by Acheson) of about 10 μm thick were applied by means of screen printing. After drying for 30
5 minutes at 80 °C, the conductive layer was cured for 30 minutes at 375 °C in an air atmosphere. The resulting resistance is about 36 Ω with a surface resistance of 0.27 Ω/\square (for 25.5 μm thick layer)

After applying a voltage the resulting heating element operates with a power density of 20 W/cm² at a substrate temperature setting of 240 °C.

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CLAIMS:

1. A film heating element, at least comprising an aluminium substrate, an electrically insulating layer which is based on a sol-gel precursor, and an electrical resistive layer with a thickness smaller than 2 μm .
- 5 2. A film heating element as claimed in claim 1, wherein the electrical resistive layer comprises an inorganic material.
3. A film heating element as claimed in claim 1 or claim 2, wherein the sol-gel precursor is a hybrid sol-gel precursor comprising an organosilane compound.
- 10 4. A heating element as claimed in claim 3, characterized in that the organosilane compound comprises methyl-trimethoxysilane or methyl-triethoxysilane.
5. A heating element as claimed in claim 1, wherein the heating element further
15 comprises a conductive layer.
6. An electrical domestic appliance comprising at least a heating element in accordance with any one of claims 1 to 5.
- 20 7. An electrical domestic appliance according to claim 6, characterized in that the electrical domestic appliance comprises a (steam) iron, a hair dryer, a hair styler, a steamer and a steam cleaner, a garment cleaner, a heated ironing board, a facial steamer, a kettle, a pressurized boiler for system irons and cleaners, a coffee maker, a deep fat fryer, a rice cooker, a sterilizer, a hot plate, a hot-pot, a grill, a space heater, a waffle iron, a toaster, an
25 oven or a water flow heater.
8. A method of manufacturing a heating element according to any one of claims 1 to 6 at least comprising the steps of providing an aluminium substrate; applying an electrically insulating layer on said substrate; and applying a resistive layer on top of the

electrically insulating layer, characterized in that the electrically insulating layer is obtained by means of a sol-gel process and the resistive layer has a thickness smaller than 2 μm .

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ABSTRACT:

The invention relates to a heating element, comprising an aluminium substrate, an electrically insulating layer, which is based on a sol-gel precursor, and an electrical resistive layer with a thickness smaller than 2 μm . The features of this heating element solve the problem of the crack formation due to a mismatch of thermal expansion coefficient of the aluminium substrate and the resistive layer. Also disclosed is an electrical domestic appliance comprising the heating element of the invention.